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SNOW CLASSIFICATION IN SUPPORT OF OFF-ROAD VEHICLE TECHNOLOGY.(U)

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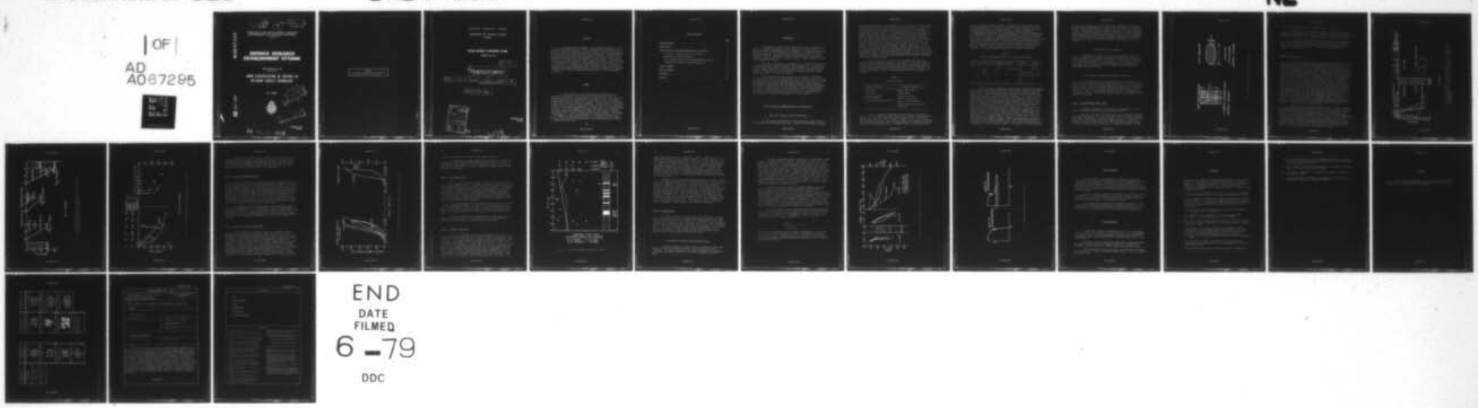

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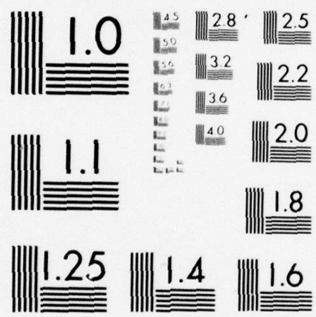
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G.J. Irwin

FEBRUARY 1979
OTTAWA

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SNOW CLASSIFICATION IN SUPPORT OF OFF-ROAD VEHICLE TECHNOLOGY

by

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OTTAWA

ABSTRACT

The present report is based on a contribution made recently to the International Society for Terrain Vehicle Systems (ISTVS) committee on Snow Mechanics Research Coordination. The International Classification System for snow and a system for metamorphosed snow are combined with field measurements to describe deposited snow in several Canadian localities. Several types of metamorphosed snow are placed in groups that are identified in terms of the structure of the snow pack, the geographic location, and the local climate. The groupings, though incomplete, are considered to provide a convenient base for describing those naturally occurring conditions which are likely to affect off-road vehicles. In support of classifying snow in terms of the physical environment, the plate penetrometer applied normally to the snow pack is recommended above other penetrometer types. The plate is however not intended to compete with currently developing methodologies for vehicle performance prediction.

RÉSUMÉ

Le présent rapport sur la coordination de la Recherche sur la mécanique pour la neige, vient d'être fait à l'intention du comité de "International Society for Terrain Vehicle Systems" (ISTVS). On a combiné le Système international de classification de la neige et celui de la neige métamorphosée, avec les mesures sur le terrain afin de décrire l'accumulation de neige dans plusieurs localités canadiennes. Plusieurs types de neige métamorphosée ont été groupés et identifiés d'après la structure de la couverture neigeuse, l'emplacement géographique et le climat local. Cette catégorisation en groupes, bien qu'incomplète, est pratique pour décrire les conditions naturelles susceptibles d'affecter les véhicules tout-terrain. L'usage du pénétromètre aide à classer la neige d'après le milieu physique, spécialement le pénétromètre à plaque (perpendiculaire à la couverture neigeuse), que l'on recommande de préférence à tout autre; cet appareil ne doit toutefois pas faire concurrence aux méthodes mises au point actuellement pour prédire le rendement des véhicules.

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INTRODUCTION

The reporting of vehicle trials and testing on snow covered terrain requires a suitable description of snow conditions in order to arrive at a useful evaluation or interpretation of performance. Such a description should draw from a classification system that can be related to details of snow/vehicle interaction. The scheme of snow classification that is to follow is intended to serve the purposes of terrain vehicles designed for travel off road while making ground contact through the use of a track, wheel, air cushion or any combination of these.

This report was based on a contribution to a recently formed committee of the International Society for Terrain Vehicle Systems (1). The committee, chaired by R.N. Yong of McGill University, was formed for the purpose of producing a standard approach to snow characterization for purposes of vehicle mobility. The report must not be construed as a committee position on the subject but rather as a view of the author.

Over the past few winters the author has carried out snow studies at Schefferville, Quebec, the Ottawa Valley, and at Wainwright, Alberta. Snow pit methods have been used to determine snow properties in a variety of natural environments during the mid-winter and spring periods. Whenever possible, tracked and wheeled vehicles were operated concurrently in areas neighbouring snow courses. In addition to snow pit methods, snow was further characterized in terms of strength by means of several designs of hand held penetrometer. As a result of such activity in what are believed to be a few geographically representative regions of Canada, an approach to snow classification and characterization is proposed for purposes of off-road mobility.

CLASSIFICATION AND CHARACTERIZATION OF THE SNOW PACK

BASIS FOR A SYSTEM OF SNOW CLASSIFICATION

The conventional running gear of tracks and wheels present familiar difficulties during interaction with snow. Problems include sinkage, ploughing,

slippage and snow adhesion or stickiness. So as to include the effect of air cushion vehicles (ACV), a snow classification scheme should take into account the additional interaction factors that are peculiar to that technology. Since the behaviour of the ACV in snow is not well known, new mechanisms of interaction will likely have to be considered as the technology develops. An attempt has been made to make the scheme to be presented general enough to allow for additional factors. The ACV/snow interaction factors that are currently known to be principally responsible for ACV drag are (a) stickiness, (b) crust break through, and (c) loss of lift in freshly fallen snow. The stickiness produces a snow build-up in front of the skirt as the ACV moves forward. This ploughing is prevalent under damp snow conditions. The relevant snow properties in this case might be cohesion, compressibility, compression (or crushing) strength, and shear strength under a known normal load. If during passage the surface crust is broken, there may be a loss of lift in the underlying snow. Hence, supportability or strength of surface crusts should be measured. Freshly fallen snow also affects ACV mobility. Hence air porosity and/or air permeability are snow properties which perhaps should be measured for purposes of classification.

It is generally accepted (2,3) that deposited snow consists of certain primary or principal properties and secondary, or derived, properties. Several of these are listed in Table I. The table gives particular emphasis to snow mechanical properties because these are most readily measurable in the field and because the interaction in question pertains to mobility. When ACV's are considered, the list of secondary properties should probably be extended.

TABLE I

Properties of Snow

Primary Properties	Secondary Properties
Grain Size	Density and Porosity
Grain Shape	Elastic Moduli
Particle Arrangement i.e. Structure	Crushing Resistance
Intergranular Bonding Type (4)	Adhesion and Cohesion
	Angle of Internal Friction
	Certain Optical and Electrical Properties

Snow is continually undergoing an alteration due to external influences in nature. Taking account of this fact in a scheme of classification should serve as an aid to characterizing the snow pack in its environment. There are at least five external factors in nature to which primary properties are particularly sensitive. These are time, temperature, temperature gradient, wind speed and overburden pressure. Changes in any of these properties are

certain to influence vehicle mobility. La Chapelle's classification system for metamorphosed snow (5) provides a convenient base from which snow variability in nature can be related to response to vehicle loading. The system, reproduced in the Appendix, divides snow into four major categories: I. Unmetamorphosed (New) Snow, II. Equitemperature or Destructive Metamorphism, III. Temperature Gradient or Constructive Metamorphism, and IV. Firnification. Such a system provides for visuallizing snow in a natural setting. It also allows for; (a) determining the direction of internal changes, and (b), inferring, with limited environmental data, its current and perhaps future properties. A subsequent step in a scheme of classification would be to make groupings of snow on a geographic base according to the most frequently observed snow conditions. From the author's experience in deep and shallow snow regions in Canada, the following general categories are proposed in Table II:

TABLE II

Groups of Metamorphic Snow Types as they Occur Naturally

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
I A,B	I III A-1 A-2 A-3	II	IV A II	I III A-3, B-3	I IV III A-1, B-1 III A-2, B-2 IV III	IV A III A-1 A-2 III A-3

With reference to La Chapelle's classification system the groupings take account of the usually layered structure of snow. Freshly fallen and wind drifted snow at the beginning of winter or before metamorphosing would comprise group 1. Subarctic woodland snow, sometimes referred to as taïga snow (6,7) in mid-winter is readily associated with group 2. The surface layer is often thick, dry and fluffy. In a typical cross section of the snow pack, the layers may or may not be distinct. However with increasing depth, the advancing stages of temperature gradient (TG) metamorphism are usually evident. Group 3 is intended to include the isothermal wet snow conditions that all snow types in the subarctic seem to approach during late spring. Group 4 might be considered a variation of group 3 with a crust at the surface. The crust could be of the melt-freeze type or formed from freezing rain. The bearing strength of this crust may become an important consideration as with vehicles crossing an ice field. Tundra snow in winter is wind packed over perhaps half of its shallow depth, but intensely metamorphosed in the lower half. Hence it is placed in group 5. Group 6 is typical of the crust layer snow packs of more temperate eastern climates where atmospheric conditions alternate between extremes throughout winter. The highly bonded layer IV thus was found to be shallow and very dry even at near freezing air temperatures in mid-winter. This was placed in group 7. The surface in the case observed

by the author possessed a thin melt-freeze crust underlain by TG snow in varying stages of metamorphism. The snow cover is evidently able to ablate without a significant intermediate stage of wet snow. There will doubtless be other snow groupings that are equally as extensive as the ones observed. However, the present groupings of snow pack structures are commonly observed in the temperate and subarctic regions visited. Other possible groupings may be found in burnt out woodland, over bogs and beside melt water streams. A more detailed account of the major groupings is presented in a later section.

DESCRIPTION OF FIELD APPARATUS

A standard NRC snow kit was used for snow pit measurements. In addition, a Rammsonde was employed for purposes of detecting a variety of layer strengths across the depth of the snow pack. Non-standard items were; (a) a hand turned centrifuge for snow samples, 4.7 cm^3 in size, (b) a vane-cone penetrometer developed by Yong and Youssef (8) of which the head dimensions are given in Figure 1, and (c), a hand held plate penetrometer whose dimensions are also given.

FIELD ORIENTED GROUPINGS OF METAMORPHIC SNOW TYPES

The present grouping of snow properties uses the language of existing and widely accepted snow classification systems (5,9). It is not the author's intent to replace existing systems, but rather to place them in the kind of natural setting that oversnow vehicles may reasonably be expected to encounter. Hence, the snow groupings are chosen in such a way as to take account of the variety of conditions that may occur when the snow pack is considered as a whole. The groupings depend generally on geographic location and time of the season.

GROUP 1 - UNMETAMORPHOSED ARCTIC SNOW

Although the author has not personally experienced snow of this group, the following general characteristics may be noted.

Type 1A is a freshly fallen snow which has not had time to undergo any further modification. It, of course, may be deep or shallow and density will change demonstrably with vehicle passage. This can be easily churned up and may cause a problem in visibility, engine ingestion or ploughing resistance. However if light and fluffy, this snow creates a special hazard to visibility rather than to energy loss in conventional vehicles. In the

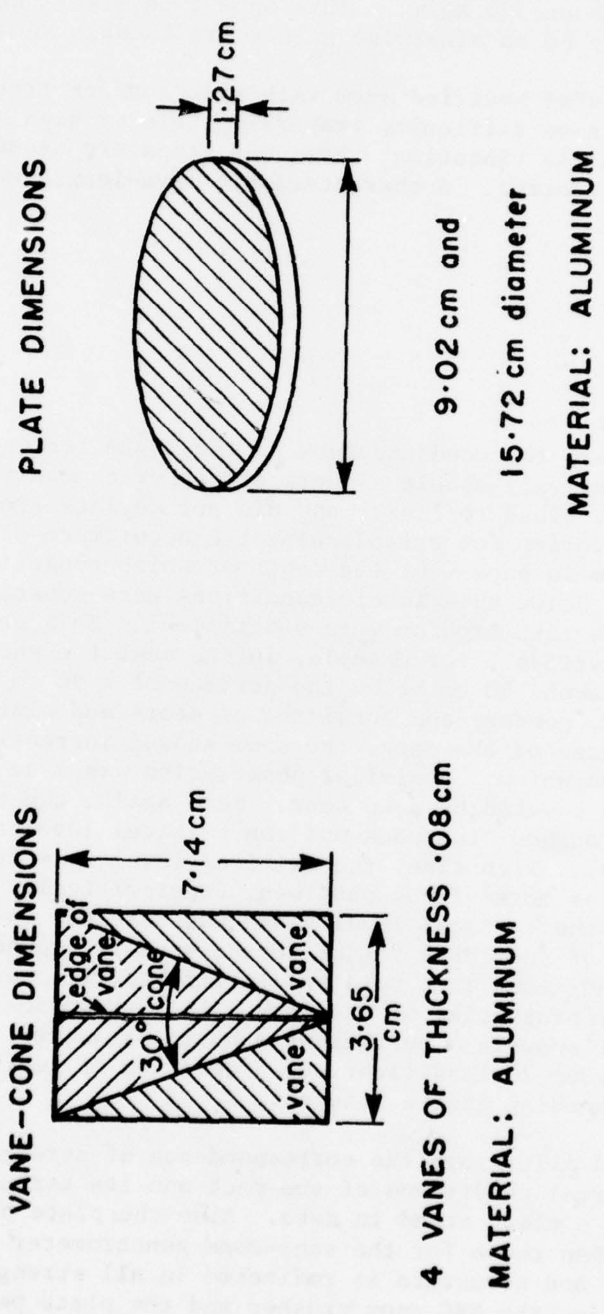

Fig. 1: Penetrometer heads used for snow testing.

case of the ACV however there is an added problem of lift air losses.

Type 1B(a) is a loess-like snow. This is a dry snow that has been wind drifted into ravines and valleys. The density is fairly uniform and probably intermediate at about 300 kg/m^3. This snow type offers an essentially linear obstacle in what may be an otherwise highly trafficable snow field.

Type 1B(b) is a wind modified snow with such surface irregularities as sastrugi. Snowmobiles have difficulty traversing this at high speed because of low frequency vehicle vibration. Frequent stops are necessary in order to maintain vehicle control. A characteristic wave-length would commonly be about 1 metre.

GROUP 2 - WOODLAND SNOW

During mid-winter, the woodland snow of the taïga region of northern Quebec appeared to be relatively stable as were atmospheric conditions. Temperature gradients were close to linear and did not deviate from linearity with time. Using the criterion for establishing the occurrence of temperature gradient (TG) metamorphism in snow (10) the depth at which conditions were critical was determined. Below this level, conditions were supercritical while above it conditions for TG metamorphism were subcritical. This corresponded approximately with observations. For example, in one case the snow above the critical level, situated about 60 cm below the surface of a 90 cm snowpack, (Figure 2) was light, dry, powdery and consisted of stars and platelets. Below this level to the base of the pack, the snow showed increasingly advanced stages of TG metamorphism. A similar observation was made in a hilly burnt out woodland region covered by deep snow. Here again, the temperature gradient was constant throughout the pack but the critical level fluctuated from day to day (Figure 3). With time, the critical level rose from midpack depth toward the surface as more of the pack went supercritical. With a substantial new snowfall the critical level again was returned to midpack depth. With a knowledge of snow base temperatures, usually around -4 to -5°C, and local atmospheric conditions in a cold stable climate, it should be possible to deduce likely properties of the snow. This is to say that the critical TG condition for snow is a sufficiently basic parameter that, under conditions typified by Group 2 classification, properties of texture and states of intergranular bonding can be deduced.

Figures 2 and 4 illustrate the correspondence of strength measured in various ways with thermal conditions of the pack and its texture. The NRC snow crushing gage shows a clear trend in data. Also the plate penetrometer data show less scatter than those for the vane-cone penetrometer and the rammsonde. Snow texture and structure is reflected in all strength measuring devices, but operationally, the NRC snow crusher and the plate penetrometer are to be preferred from the point of view of ease of handling and an inherent averaging effect. In later work vanes were attached to the plate. In such a case it is proposed that new intergranular bonds were formed under vertical pressure followed by a rupturing of those bonds in the shearing mode. This does not appear to readily occur in the use of the vane-cone.

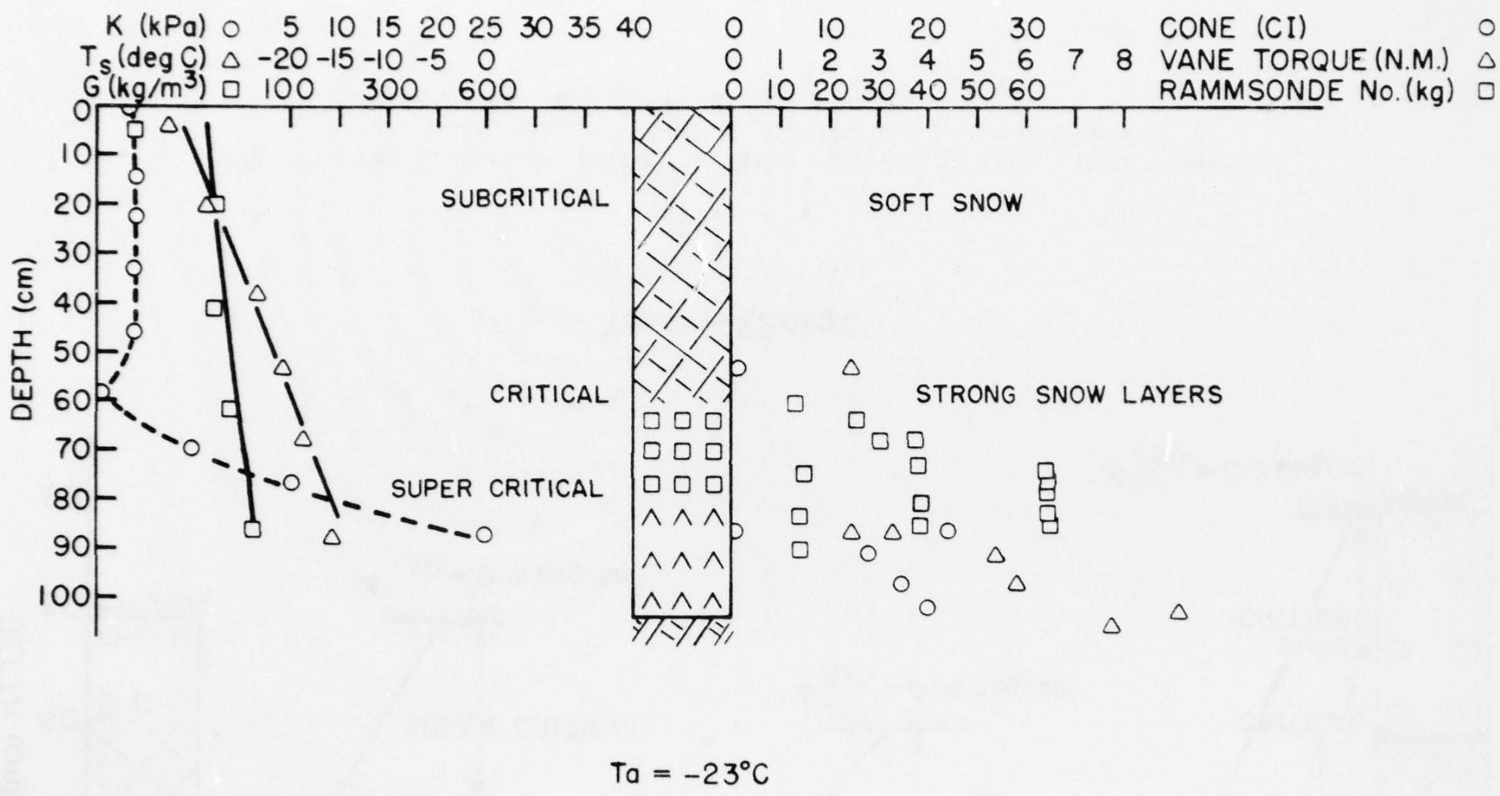

Fig. 2: *Snow pit measurements in Northern Woodland. Note K refers to NRC snow crushing gage, T_s is snow temperature, Ta is air temperature, G is snow density. See Reference 9 for explanation of snow pit cross section.*

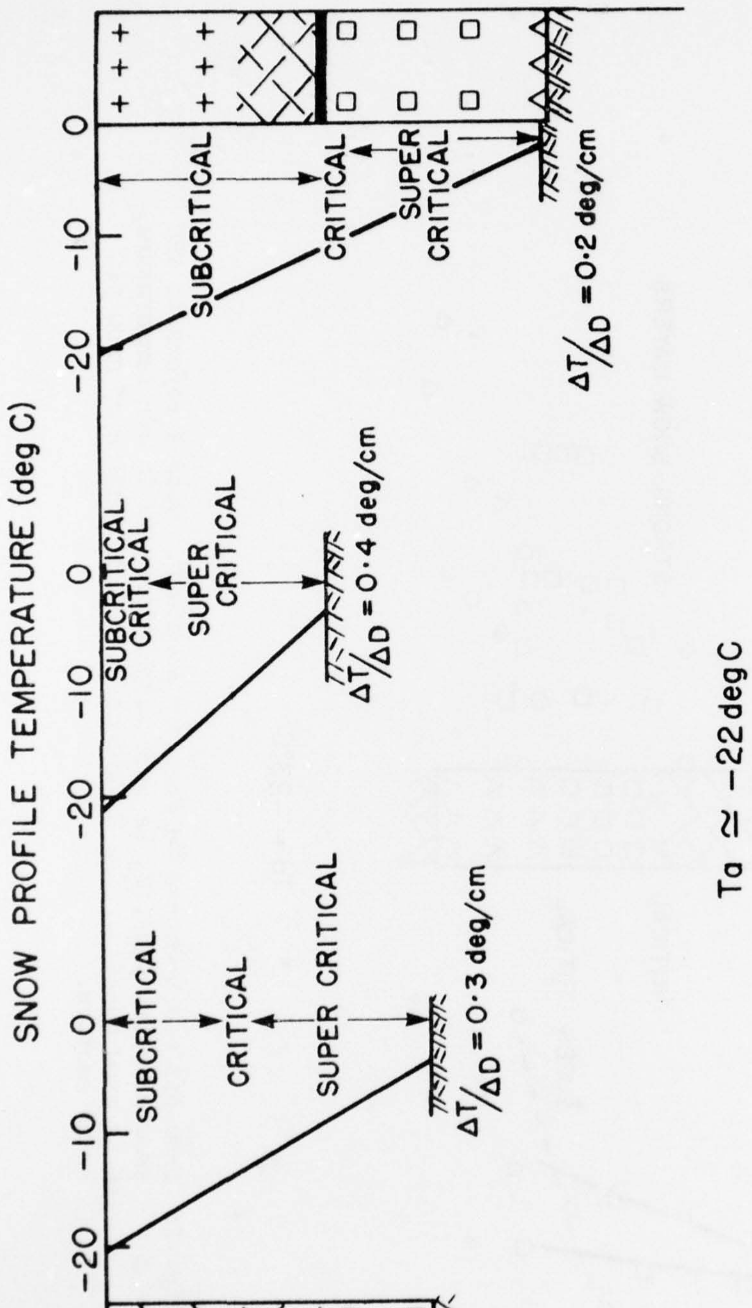

Fig. 3: Temperature profiles for three successive days. Note there is some correspondence between conditions for constructive metamorphism and observed snow texture.

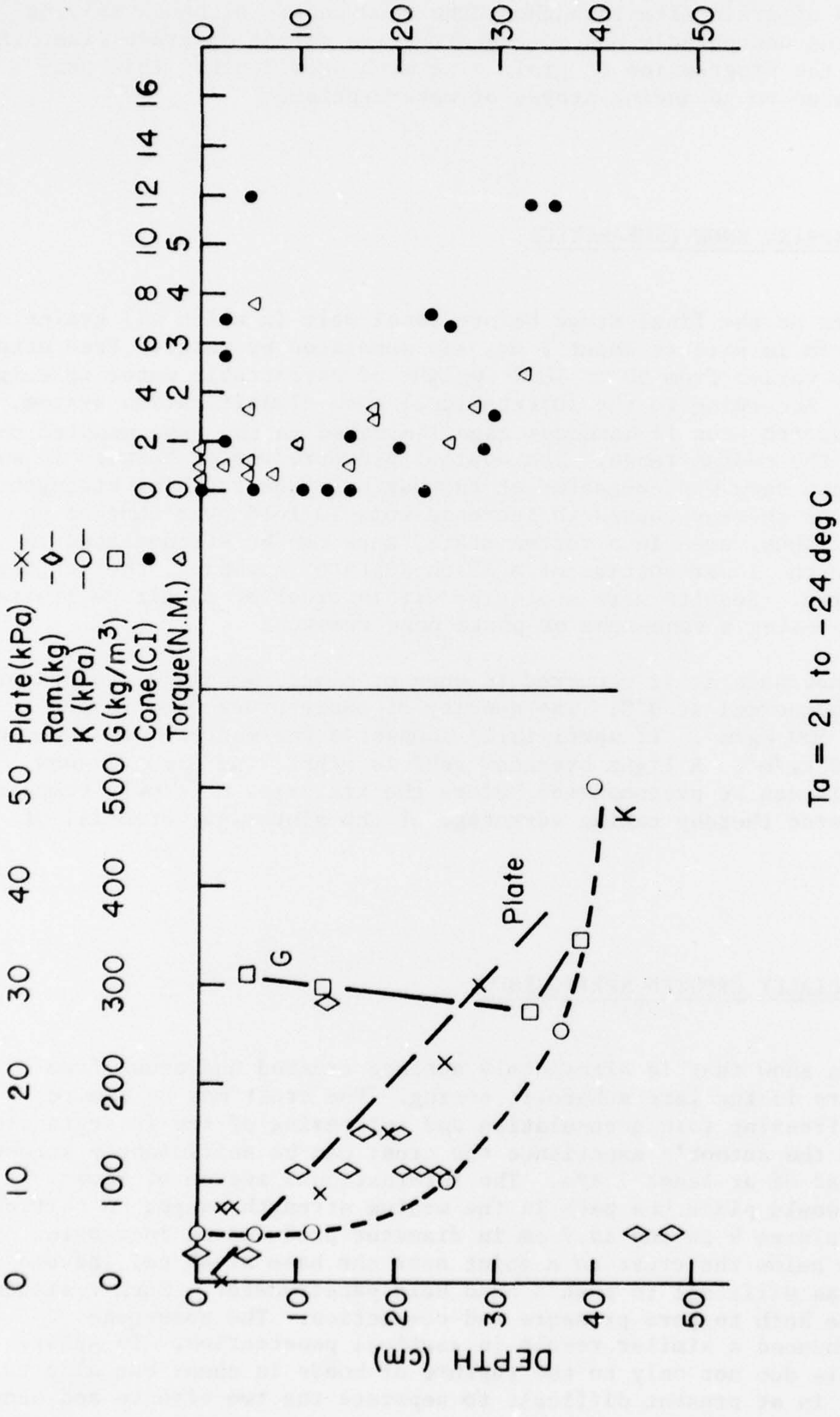

Fig. 4: Snow pit measurements in a northern burnt-out woodland.

The density of settled snow was usually observed to increase from below the surface at 200 kg/m^3 to the base at 300 kg/m^3. Note in Figure 5 the distribution of grain size throughout the snow pack. Although seiving of dry snow grains undoubtedly has some destructive effect on grain size, it does illustrate the progression of grain size with snow depth. This progression is related to advancing stages of metamorphism.

GROUP 3 - LATE SPRING SNOW (SUBARCTIC)

This is at the final stage before total melt in which all grains are spherical, uniform in size at about 2 mm, and separated by water. Free water content commonly varied from 50 to 100% (weight of extractable water to weight of snow solid). According to the international snow classification system, the National Research Council hardness gage indicated in the case studied that strength was in the medium range. The applied pressure varied between 10 and 100 kPa. When the snow was compacted at the surface, the crushing strength at the surface was thereby caused to increase some 10 fold over that of undisturbed snow. Thus, even in a rotten state, snow can be strengthened to some extent. In the lower portion of a 45 cm depth of snowpack, the strength remained unaltered. Results were scattered within order of magnitude limits as were the data using a vane-cone or plate penetrometer.

The snow pack as it occurred in open or closed woodland, tundra or over bog, was isothermal at 0°C. The density of undisturbed snow ranged between 400 and 500 kg/m^3. If surficially compacted the surface density could be raised to 680 kg/m^3. A light oversnow vehicle might find Group 3 snow trafficable if it can be precompacted before the traverse, or slowly compacted during the traverse thereby taking advantage of the sintering potential of such snow.

GROUP 4 - SURFICIALLY CRUSTED SPRING SNOW

Rotten snow that is alternately surface crusted and crust free frequently occurs in the late subarctic spring. The crust may be due to driving winds, freezing rain accumulation and refreezing of the intergranular melt water. In the author's experience the crust can be sufficiently strong to support a load of at least 7 kPa. The international system of snow classification would place the pack in the medium strength range. A vertical indentation of plates 9 cm and 15.7 cm in diameter produced an increasing resistance from below the crust to a point near the base at 45 cm. Beyond this depth it was difficult to push a hand held penetrometer. Such resistance was probably due both to pore pressure and compaction. The vane-cone penetrometer produced a similar result in vertical penetration. In shear, the resistance is due not only to the rupture of bonds in shear but also to compaction. It is at present difficult to separate the two effects and hence

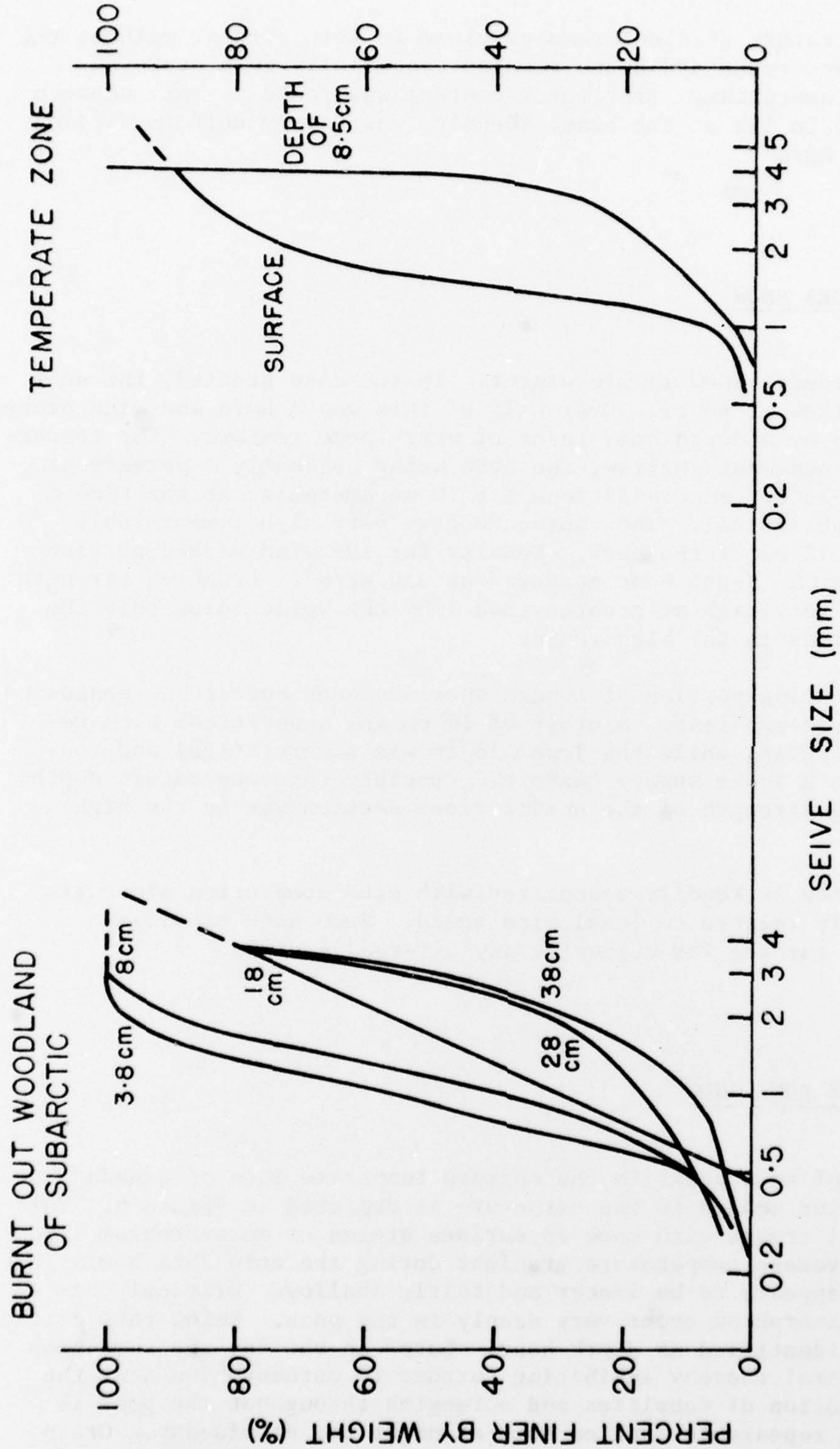

Fig. 5: Observed grain size distributions in snow packs using seives.

values have been recorded in terms of torque (Newton-metres).

The temperature gradient remains close to zero with or without the presence of a surface crust and hence remains essentially in a state of equitemperature metamorphism. Free water content was found to vary between zero at the surface to 15% at the base. Density was fairly uniform varying between 440 to 490 kg/m^3.

GROUP 5 - COLD TUNDRA SNOW

This is tundra snow in mid winter. In the case studied, the snow was relatively shallow at 43 cm. Over half of this was a hard and wind packed top layer underlain by a depth hoar layer of very loose texture. The temperature gradient was somewhat shallow, the base being evidently a permafrost area currently at -18°C. The conditions for TG metamorphism at the time of measurement were subcritical. The rammsonde gave very high immeasurable values for the top 12 cm of the pack. Density for the wind packed portion was 475 kg/m^3 while the depth hoar measured as 310 kg/m^3. Crushing strength of the surface was very high at greater than 1000 kPa while below this the depth hoar gave values in the high range.

A neighbouring portion of tundra snow was much softer but possessed a steeper temperature gradient. A crust of 10 cm was subcritical with respect to TG metamorphism, while the lower 18 cm was supercritical and consisted of snow with a loose sugary texture. Possibly this was mature depth hoar. The crushing strength of the entire cross section was in the high range.

Tundra snow is readily associated with wind compaction since its hardness is probably related to local wind speed. Such snow provides a highly trafficable surface for virtually any off-road vehicle.

GROUP 6 - TEMPERATE ZONE SNOW

Typical of snow packs in the eastern temperate zone of Canada throughout the winter season is the structure as depicted in Figure 6. This consists of several crusts with snow in various stages of metamorphism lying in between. The average temperature gradient during the cold dark hours in the example shown appears to be linear and fairly shallow. Critical conditions for TG metamorphism occur very deeply in the pack. Below this critical level is what was identified as depth hoar. Later in the day the snow goes essentially isothermal thereby inhibiting further TG metamorphism near the base. The distribution of densities and strengths throughout the pack is scattered but in a repeatable fashion both at night and at mid-day. Grain size distribution is highly divergent between the surface and base of the pack as indicated in Figure 5. The coarsest grains are at the base. Free

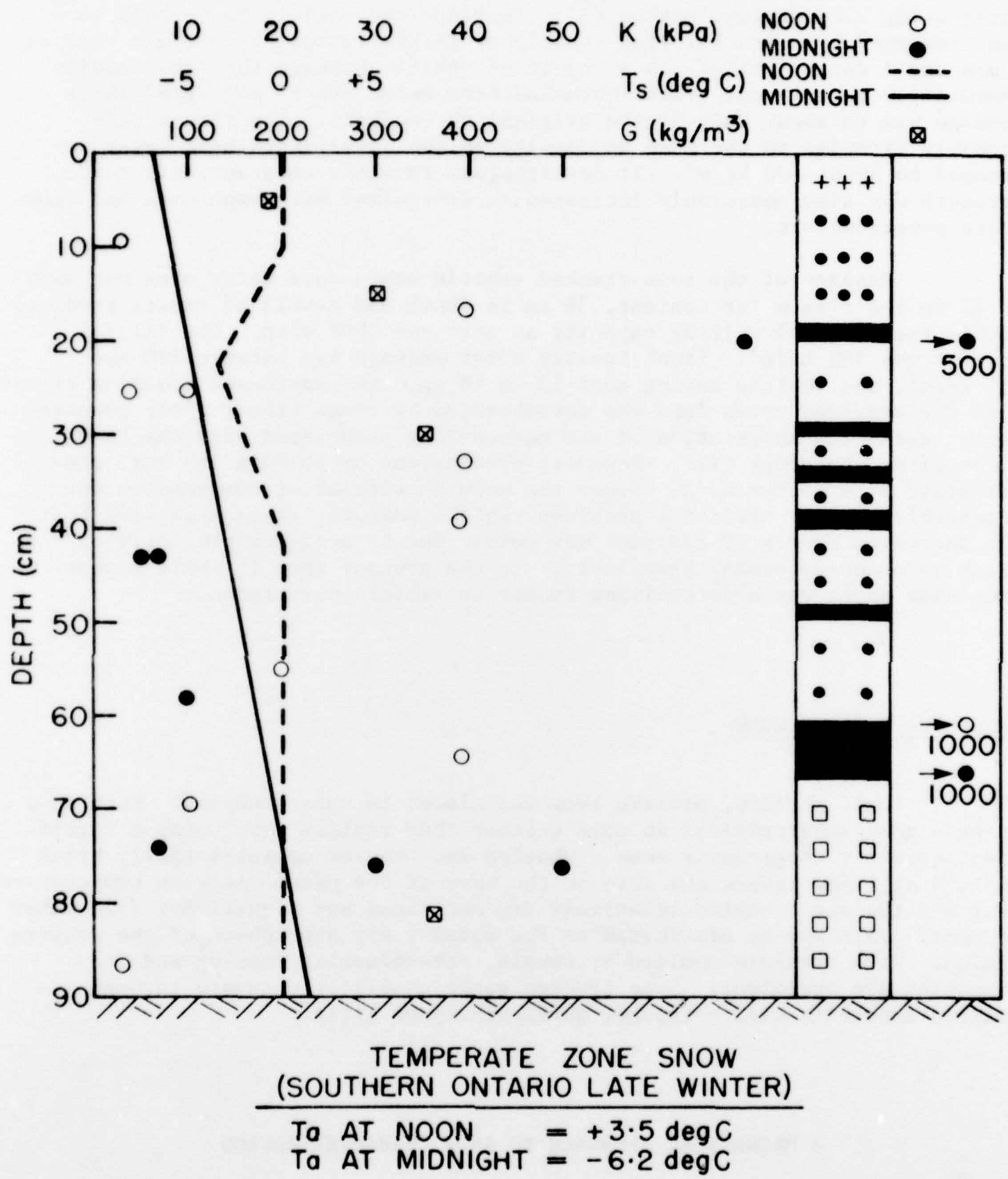

Fig. 6: Snow pit measurements taken near Ottawa.

water content was measured by a calorimetric method. However, more reproducible results at 4% were obtained in snow of a similar condition a year later using a centrifuge method (11). During some vehicle tests this snow was traversed by a track laying vehicle of 14 kPa footprint pressure at 2 to 4 m/s and 1 deg. of trim. As a result of vehicle passage the snow density immediately beneath the track increased from about 300 to 640 kg/m^3 while sinkage was to about half of the original 60 cm depth. The stress bulb probably extended to the base as density in the basal depth hoar layer increased to about 400 kg/m^3. It nevertheless remained substantially loose. Strength was also measurably increased as determined with vane-cone and vane-plate penetrometers.

Passage of the same tracked vehicle seven days later over wet snow of 25 to 60% free water content, 38 cm in depth and devoid of crusts produced double the original pulling capacity at zero and 100% slip. The initial density was 400 kg/m^3. Final density after passage was between 690 and 640 kg/m^3, the vehicle having sunk 13 to 18 cm. The increased tractive effort over the previous seven days was corroborated by conventional plate penetrometer tests with application of the methodology associated with the Land Locomotive Laboratory (12). However, predictions by calculation were conservative by a factor of 3. Since the snow density after compression was comparable to that after the previous vehicle passage, it is suggested that the increased source of traction was mainly due to a closer proximity of the track to a non-deforming base layer. In the present case it would appear that snow depth was a determining factor in vehicle performance.

GROUP 7 - PRAIRIE SNOW

Dry, shallow, prairie snow was placed in this grouping. Such snow quickly goes supercritical in cold weather thus rapidly developing a significant quantity of granular snow. Wheeled and tracked vehicles easily break through all snow layers and slip at the base of the pack. At warm temperatures near 0°C the snow remains relatively dry and lacks any significant free water content. This may be attributed to the usually dry atmosphere of the prairie region. With pressure applied by wheels, intergranular bonding and ice formation are prevalent. Some tracked vehicles easily excavate through prairie snow with high slippage, particularly on hills.

A MECHANICAL APPROACH TO SNOW CHARACTERIZATION

The above groupings may serve to describe conditions of snow cover. However for practical reasons the number of test instruments should be minimized. The simplest approach to snow characterization and ultimately to correlation with vehicle performance over snow is probably by mechanical means.

The plate penetrometer applied vertically to the snow surface shows promise as a simple mechanical means for establishing a characteristic condition by compressing it to the point of the onset of plastic flow. This point could constitute a standard condition. Recent tests with a variety of penetrometer plate sizes in soft snow and vehicle compacted snow support other work (4) on the existence of a plastic condition for snow. Results of these tests are depicted in Figure 7. Depth has been normalized for purposes of comparison between snow covers in different states of compaction. It is evident from the figure that for consistency in results, large plate sizes ("b" in the figure) are to be preferred. It is also apparent that soft snow, like compressible soils (13) may be compressed through a region of local volumetric change followed by a local geometric or plastic change. In the plastic condition snow is effectively incompressible for the usual range of foot print pressures of over snow vehicles.

As a test device the plate has a notable advantage over other penetration devices in that it affects a sufficiently large volume of snow to provide a measure of its bulk properties. Snow placed in a standard condition at a suitably slow rate of deformation or penetration may be considered as a precondition for further thrust and penetration tests with other devices for purposes of vehicle performance prediction. However, until prediction methodology is firmly established, use of the plate as a simple characterization device deserves further consideration. Depending on the local stratigraphy of the snow and the strength of crusts, the shape of the pressure depth curve for a given penetration rate may suitably describe snow conditions to which other mechanical tests can be related.

By way of example, the two graphs of Figure 8 show pressure-depth curves for two snow packs. One has a thick upper layer while the other has a relatively shallow upper layer subtended by a strong crust layer. The point of onset of plastic flow corresponds to a point of inflection or a minimum in the rate of change of slope, i.e.

$$\left.\frac{d^2\sigma}{dz^2}\right|_{\substack{\sigma = \sigma_c \\ Z = Z_c}} = 0$$

where σ is applied pressure and z is depth of penetration of a plate into the snow pack. Since an equation of state is not available for snow in the present context, a pressure-depth curve as obtained in the above deformation experiment along with a supporting description of snow conditions may serve in its place.

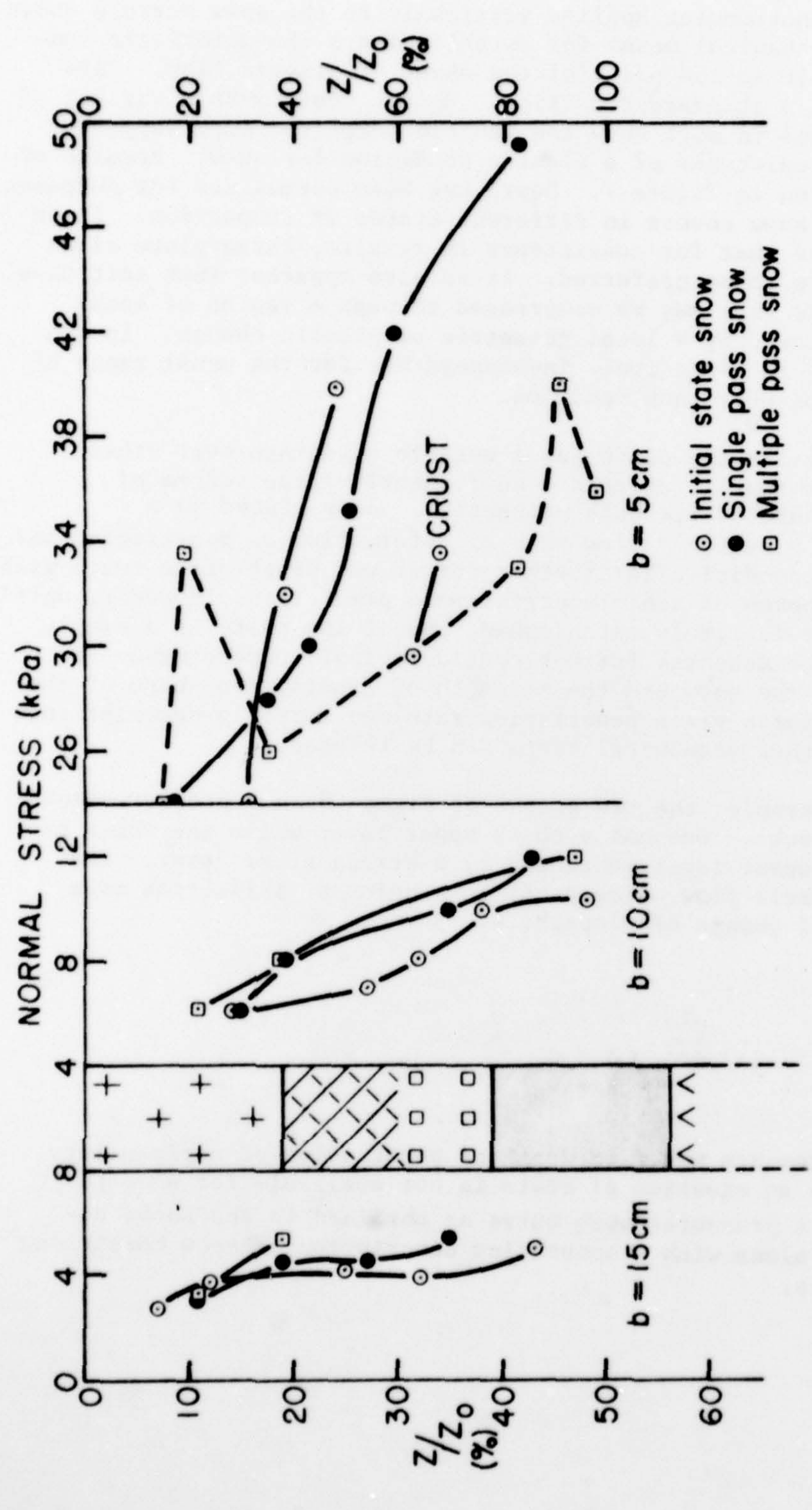

Fig. 7: Vertical strength profiles for several plate diameters.

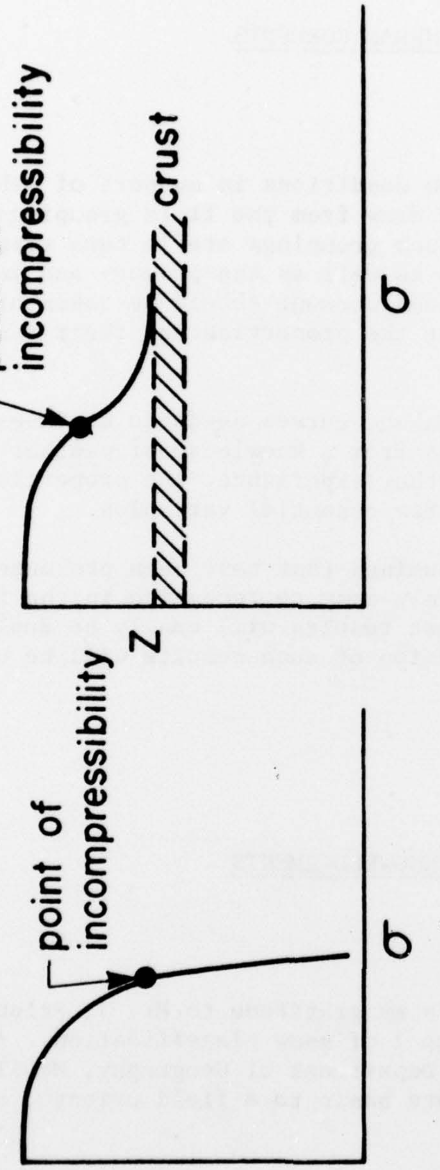

Fig. 8: Pressure-depth curves at two snow packs.

GENERAL COMMENTS

The description of snow conditions in support of vehicle and penetrometer test results should draw from the field groupings presented and no doubt many more groupings. Such groupings are in turn supported by measurements of external factors as well as the primary and several of the secondary properties of snow. Some account should be taken of the ephemeral nature of snow by noting how fast the properties and their response to methods of testing change.

The use of pressure sinkage curves needs to be investigated as does the prediction of snow properties from a knowledge of weather conditions, season and snow depth. With further experience, the properties requiring measurement may be reduced to a few essential variables.

The classification groupings that have been presented cover broad categories but should be relatively easy to recognize in the field. It is hoped therefore that reported test results will easily be duplicated and verified and that the interpretation of such results will be unequivocal.

ACKNOWLEDGEMENTS

I would like to express my gratitude to Mr. J. Pilon of DND/DLOR for his assistance with the Group 1 of snow classification. Acknowledgement is also due to Mr. H. Granberg, Department of Geography, McGill University, who suggested some of the concepts basic to a field oriented system of snow classification.

During the course of snow studies much logistic support and advice was gained from McGill Sub-Arctic Research Laboratory at Schefferville, DND/LETE at Orleans, Ontario and DND/CFB, Calgary at Wainwright, Alberta.

The difficulties of air cushion travel over snow were identified to the author by Mr. H. Fowler of National Research Council. For this I express much appreciation.

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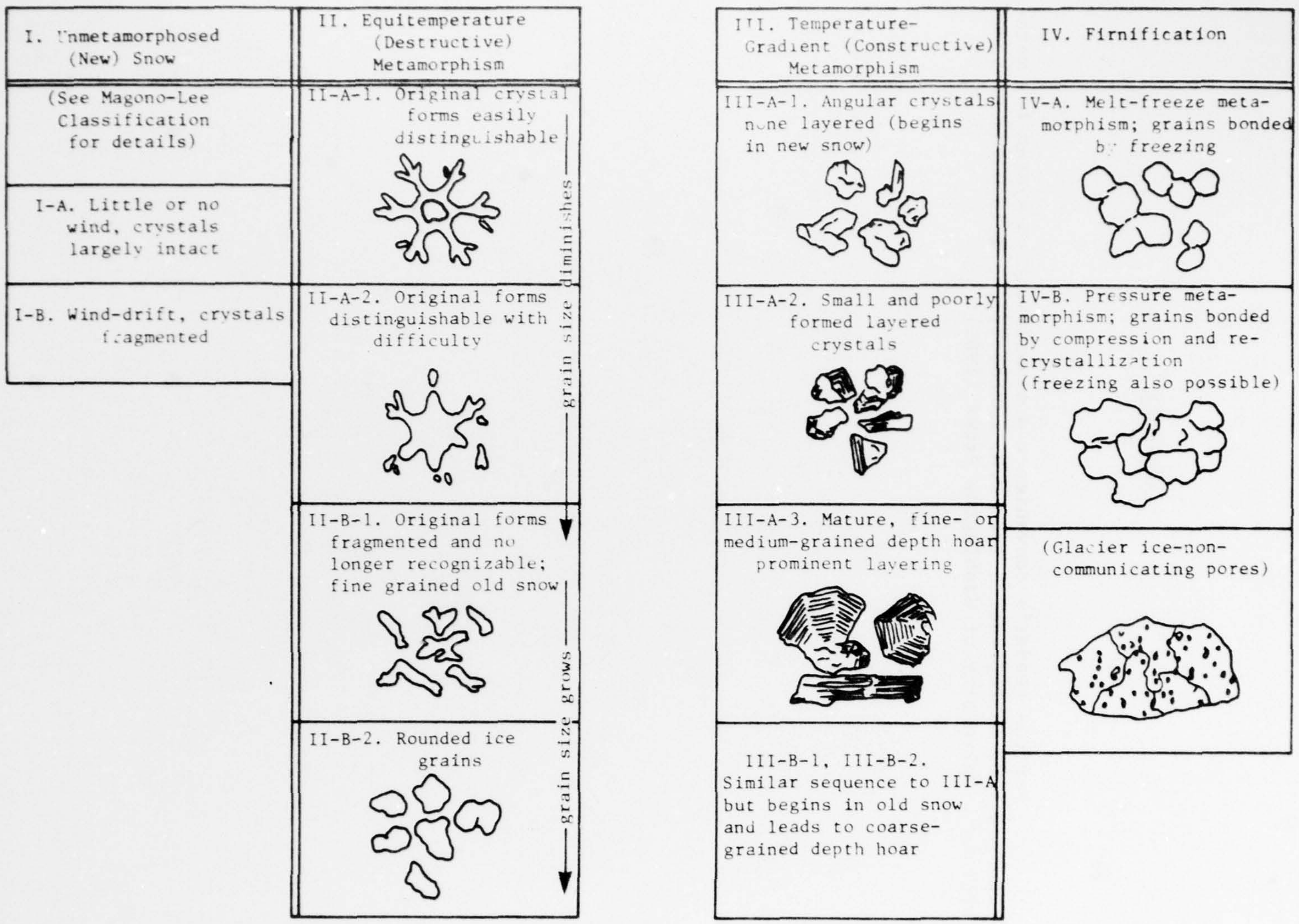
APPENDIX

For the reader's convenience a classification system for metamorphosed snow is reproduced from E.R. LaChapelle, "Field Guide to Snow Crystals", University of Washington Press (1969).


I. Unmetamorphosed (New) Snow
(See Magono-Lee Classification for details)
I-A. Little or no wind, crystals largely intact
I-B. Wind-drift, crystals fragmented
II. Equitemperature (Destructive) Metamorphism
II-A-1. Original crystal forms easily distinguishable
II-A-2. Original forms distinguishable with difficulty
grain size diminishes
II-B-1. Original forms fragmented and no longer recognizable; fine grained old snow
II-B-2. Rounded ice grains
grain size grows
III. Temperature-Gradient (Constructive) Metamorphism
III-A-1. Angular crystals none layered (begins in new snow)
III-A-2. Small and poorly formed layered crystals
III-A-3. Mature, fine- or medium-grained depth hoar prominent layering
III-B-1, III-B-2. Similar sequence to III-A but begins in old snow and leads to coarse-grained depth hoar
IV. Firnification
IV-A. Melt-freeze metamorphism; grains bonded by freezing
IV-B. Pressure metamorphism; grains bonded by compression and recrystallization (freezing also possible)
(Glacier ice-non-communicating pores)

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13. ABSTRACT

The present report is based on a contribution made recently to the International Society for Terrain Vehicle Systems (ISTVS) committee on Snow Mechanics Research Coordination. The International Classification System for snow and a system for metamorphosed snow are combined with field measurements to describe deposited snow in several Canadian localities. Several types of metamorphosed snow are placed in groups that are identified in terms of the structure of the snow pack, the geographic location, and the local climate. The groupings, though incomplete, are considered to provide a convenient base for describing those naturally occurring conditions which are likely to affect off-road vehicles. In support of classifying snow in terms of the physical environment, the plate penetrometer applied normally to the snow pack is recommended above other penetrometer types. The plate is however not intended to compete with currently developing methodologies for vehicle performance prediction.

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